Epidemiology of Battle-Damaged Fixed-Wing Aircraft

Major Trent A. Greenwell
Department of Engineering Mechanics
2354 Fairchild Drive, Suite 6K-139
USAF Academy, Colorado, USA 80840

trent.greenwell@usafa.edu

ABSTRACT

Battle damage is a natural side effect of armed conflict. History shows the prevalence of aircraft battle damage varies based on the nature of the conflict. Aircraft battle damage repair allows an aircraft fleet to remain viable while remaining engaged in the conflict at hand. The US Air Force's experience with aircraft battle damage and aircraft battle damage repair dates back to World War II and has seen a number of changes to affected aircraft populations during subsequent lesser conflicts. The Israeli Air Force and British Royal Air Force also have a distinct history with aircraft battle damage leading them to their own unique approaches to ABDR. Recent US battle damage data reflects how the nature of a conflict can affect battle damage symptoms and populations.

1.0 INTRODUCTION

Aircraft battle damage is an unavoidable reality during military actions. History shows varied degrees of battle damage among major conflicts involving military aircraft, from World War I (WWI) to World War II (WWII) to several lesser conflicts in more recent history. Aircraft battle damage repair (ABDR) is critical to maintaining a viable aircraft fleet in times of conflict. A number of different approaches to aircraft battle damage repair have been applied in these different conflicts. Data from these different conflicts reflect a compelling need to sustain an established ABDR program to maintain viable combat aircraft fleets during hostilities.

2.0 HISTORICAL PERSPECTIVE OF BATTLE DAMAGE AND REPAIR

2.1 Battle Damage and Repair before Vietnam

While substantive data on battle damage and repair thereof have not been recorded until conflicts after WWII, it is known that battle damage and battle damage repair were prevalent in both WWI and WWII. Relatively low-performance WWI aircraft with shrapnel holes in their purely aerodynamic fabric skins proved easy to repair with simple adhesive patches. There are records of the French using old tractor parts to repair battle damaged mechanical components of their aircraft during WWI [1]. WWII brought new advances in aircraft design and construction which brought with them the need for more elaborate repairs. WWII era aircraft were more highly-engineered than their WWI predecessors and used semi-monocoque designs with formed metal skins that required not only aerodynamic patching, but also restoration of design strength and stiffness. The perceived level of intensity of the conflict and threat prompted different approaches to ABDR by different nations involved in WWII. Under dire threat of attack during the Battle of Britain, the British Royal Air Force (RAF) developed procedures for rapid, temporary aircraft repairs and mobilized civilian machine shops and repair garages to assist in repair and fabrication of aircraft parts [1]. The German Luftwaffe, with a more relaxed threat condition in the early years of the war, established a standard of crating and shipping aircraft with greater than 40% damage back to their manufacturer for full repair to like-new condition [1]. The US Army Air Corps bomber fleet, which suffered tremendous

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
MAY 2010	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Epidemiology of Battle-Damaged Fixed-Wing Aircraft	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Engineering Mechanics 2354 Fairchild Drive, Suite 6K-139 USAF Academy, Colorado, USA 80840**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA564486. Battle Damage Repair Techniques and Procedures on Air Vehicles - Lessons Learned and Prospects. RTO-EN-AVT-156, The original document contains color images.

14. ABSTRACT
Battle damage is a natural side effect of armed conflict. History shows the prevalence of aircraft battle damage varies based on the nature of the conflict. Aircraft battle damage repair allows an aircraft fleet to remain viable while remaining engaged in the conflict at hand. The US Air Forces experience with aircraft battle damage and aircraft battle damage repair dates back to World War II and has seen a number of changes to affected aircraft populations during subsequent lesser conflicts. The Israeli Air Force and British Royal Air Force also have a distinct history with aircraft battle damage leading them to their own unique approaches to ABDR. Recent US battle damage data reflects how the nature of a conflict can affect battle damage symptoms and populations.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**10**	

losses throughout the war, so frequently received battle damage that repair crews undertook battle damage repair in much the same way they undertook routine maintenance actions after every flight. Figure 1 shows the type of damage commonly experienced by USAF bombers.

Figure 1: USAF WWII Bomber Battle Damage (reprinted with permission from [2]

In stark contrast to the USAF experience in WWII, the US experience in Korea required very little ABDR due to the rapid establishment of air superiority. The first real need of the USAF to implement substantial ABDR practices after WWII did not occur until the Vietnam War, where the US was caught initially unprepared.

2.2 The U.S. ABDR Experience in Vietnam

The U.S. Air Force (USAF) in Vietnam suffered considerable aircraft damage and losses for the first time since World War II. Of the more than 21,000 aircraft committed to the conflict, 23% were lost due to a multitude of reasons including combat losses, 21% emerged from the war undamaged, and the remaining 56% returned to base with combat damage [3]; an example of Vietnam-era combat damage is shown in Figure 2. Vietnam marked the first comprehensive collection and analysis of battle damage and repair statistics by the USAF. Final statistics show a 4:1 combat damage to combat loss ratio [1]. Initially, the USAF was unprepared for the demands of substantial battle damage. From 1955 to 1965, ABDR was conducted by civilian defense contractor field teams. In 1965, in response to a request for crash damage repair support, the USAF formed Rapid Area Maintenance (RAM) teams of highly skilled government repair technicians and engineers from stateside USAF repair depots. RAM teams performed all levels of maintenance deemed either highly complex or requiring more than five days to complete. They also conducted ABDR. Deploying RAM teams comprised predominantly of civilians into combat zones quickly proved difficult due to greater travel expenses required for civilians than military, the civilian's right to refuse dangerous work, and the difficulties in justifying civilian combat casualties to the general public. These difficulties with RAM teams led to the creation of special teams of all-military maintenance technicians, logisticians, and engineers managed under Combat Logistics Support Squadrons (CLSSs) starting in 1967 [1]. Combined actions by CLSS and RAM teams returned 1000 of Vietnam's 11,800

battle-damaged aircraft to the war using ABDR tools and techniques; 59% of these aircraft were repaired in 48 hours or less [1].

Figure 2: USAF F-4 Combat Damage in Vietnam (reprinted from open source)

2.3 The Israeli ABDR Experience in the Yom Kippur War

The Yom Kippur War of 1973 highlighted the extreme importance of ABDR in a contentious conflict and demonstrated the expert ABDR practices of the Israeli Air Force (IAF). The IAF had established a robust ABDR program prior to the Yom Kippur War stemming from their experience in the 6-Day War of 1967 and logistics planning and analyses conducted from lessons learned in that conflict. The IAF approach to ABDR planning involved thorough analysis to prepare combat spares kits for their aircraft equipped for the types of damages experienced in combat versus simply amplifying peacetime spares kits. The IAF also incorporated ABDR into their aircraft refit process, so all aircraft returning from combat sorties would be refuelled, rearmed, and repaired at the same time within the same shelter, thereby minimizing unproductive downtime. IAF ABDR assessment and design was conducted by engineers assigned to maintenance units and supported by highly-skilled depot technicians all located at the operational bases, allowing for all levels of repair to be conducted on-site within the refit shelter. Using this well-thought-out and efficient approach to ABDR, the IAF was able to achieve a 72% repair rate in 24 hours or less [1]. Statistics show a 3:1 damage to loss ratio in the early days of the war dwindling to 7:1 later in the war as the IAF recovered from the initial surprise attack and mobilized their reserve forces [4]. Figure 2 illustrates the IAF's effective use of ABDR over the first 15 days of the 21 day war. ABDR Experts claim that "without effective rapid repairs, the Israeli Air Force would have been out of business by the eighth day of the conflict" [1]. The IAF published four key ABDR lessons learned from their experiences in the Yom Kippur War:

1. Skilled ABDR teams must be available from the beginning of the conflict.
2. Rapid and thorough battle damage assessment is the key to a successful ABDR program – assessors must be highly experienced and possess extensive structural knowledge.
3. Each instance of battle damage is unique, requiring creativity, skills, and experience from the ABDR team members.
4. Major modular replacement spares were critical and many repairs could not have been performed without them [1].

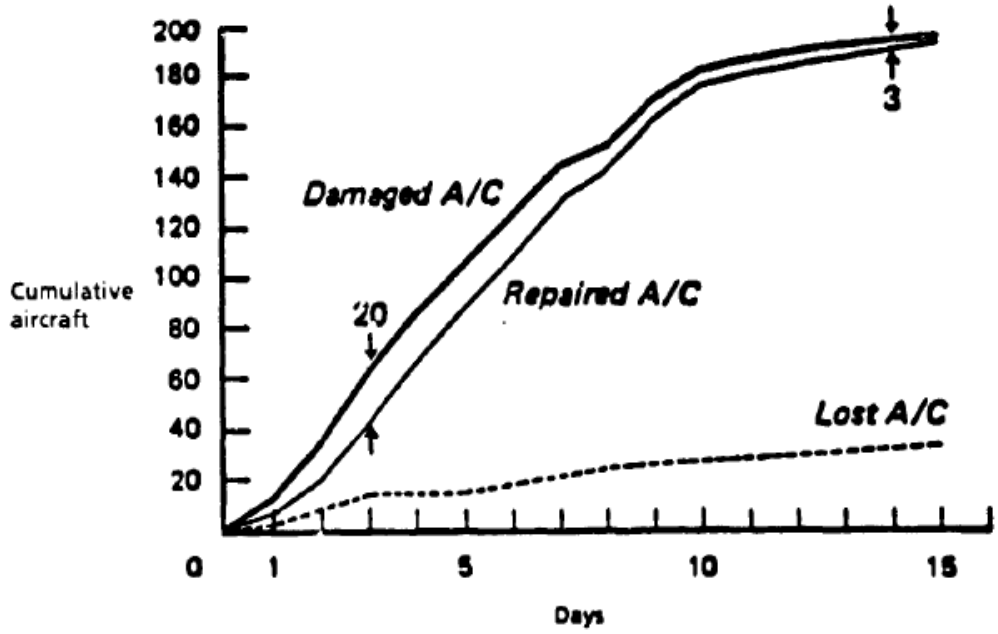

Figure 3: IAF Aircraft Damage/Repair/Loss vs Days of Conflict (Reprinted from [4])

2.4 The British ABDR Experience in the Falkland Islands War

While specific ABDR data on the RAF combat experience in the 1982 Falkland Islands War are not available, ABDR was critical to the effort. According to one source, "Every Royal Air Force GR Mk-1 Harrier committed to fight had to be [combat damage] repaired at least once" [1]. This reflects a 100%-plus combat damage rate for the aircraft engaged in the conflict. The Falkland Islands War was the first test of the RAF's newly formalized ABDR program, established in 1976 using lessons learned from the USAF experience in Vietnam and the IAF experience in the Yom Kippur War. The RAF published a list of 14 lessons learned from their experiences in this conflict:

1. Future aircraft should be designed for survivability.
2. Manuals are for guidance only.
3. Initiative and ingenuity count for a lot.
4. Some documentation is still important.
5. Go/No Go lists are important.
6. Additional spares are necessary to support ABDR.
7. Access holes need to be cut for assessment and/or repair.
8. Robbing from damaged aircraft is very much a part of ABDR.
9. Kits are essential for land operations.
10. Transparency (canopy) repair methods are lacking.
11. Repairs should be the best possible in the time available.
12. Self-sealing fuel tanks are needed.
13. The pilot is not always aware that damage has occurred.
14. Assessment is very important – the assessor is the key man [1].

2.5 The USAF ABDR Experience in Operation Desert Storm

Like the RAF's experience in the Falkland Islands War, the USAF first tested its current ABDR program shortly after its formalization in 1981 during the 1991 Gulf War. This ABDR program, which remains largely unchanged now, drew from the lessons learned by the USAF in Vietnam, the IAF in the Yom

Kippur War, and the RAF in the Falkland Islands War. The USAF ABDR program capitalizes on the existence of established CLSS teams with the incorporation of specially-trained depot engineers, standardized ABDR tool and material "wagons", and robust ABDR manuals which allow a blend of the rapid temporary repairs preferred by the RAF as well as the engineer-designed permanent repairs preferred by the IAF. Data for the A-10 Thunderbolt II employment during Operation Desert Storm plotted in Figure 4 show that the A-10 required the most ABDR of any US aircraft in the conflict [5]. Of the 144 A-10s committed to the conflict, 70 were damaged and 5 were lost resulting in an A-10 specific damage to loss ratio of 14:1 [1]. This exceptionally high damage to loss ratio is due in large part to the A-10 being designed to be highly survivable using survivability data compiled in previous conflicts. The final statistics from the war show a repair rate roughly that of the USAF in Vietnam, as seen in Figure 3.

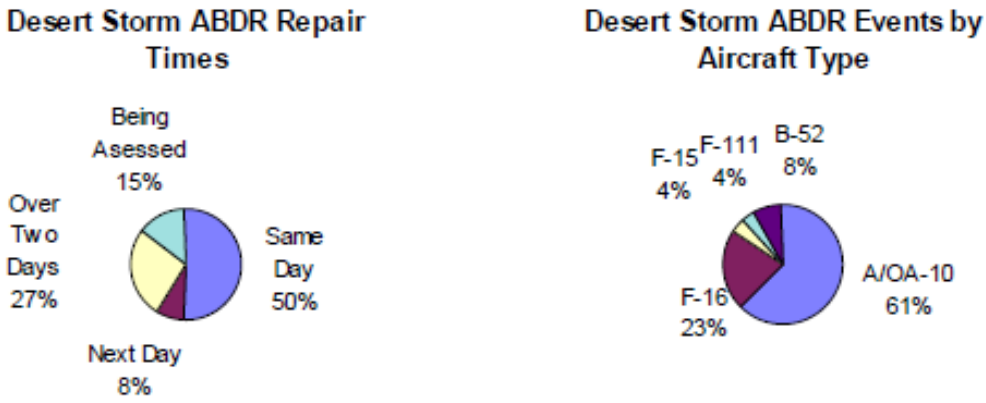

Figure 4: Operation Desert Storm ABDR Times and Events (Reprinted from [5])

3.0 CURRENT EPIDEMIOLOGY OF FIXED-WING BATTLE-DAMAGE

Recent US battle damage data compiled by the US Survivability/Vulnerability Information Analysis Center (SURVIAC) from mid-1998 to December 2009 is shown in the figures 5-9. As seen in Figures 5-8, the vast majority of battle damage over the last 12 years has occurred on rotary wing platforms. This is as expected in a conflict where air superiority has been so quickly achieved and the bulk of battle damage is inflicted from ground-based threats on slower, low-flying aircraft like helicopters and cargo aircraft. Helicopter damages and losses are included to illustrate that air superiority and low-fixed wing battle damage rates do not negate the need for ABDR. Note that the balance of battle damage by aircraft type is more evenly distributed in conflicts with contested airspace, as seen in Figure 8 during 1999 where the US experienced roughly equal numbers of damaged fighter/attack, cargo, and helicopter aircraft and more than double the number of lost fighter/attack aircraft than cargo or helicopter aircraft in the same conflict. Figure 9 shows fixed-wing specific damages by type and year since 1998; note that there have been no fighter/attack damages or losses due to battle damage since 2005.

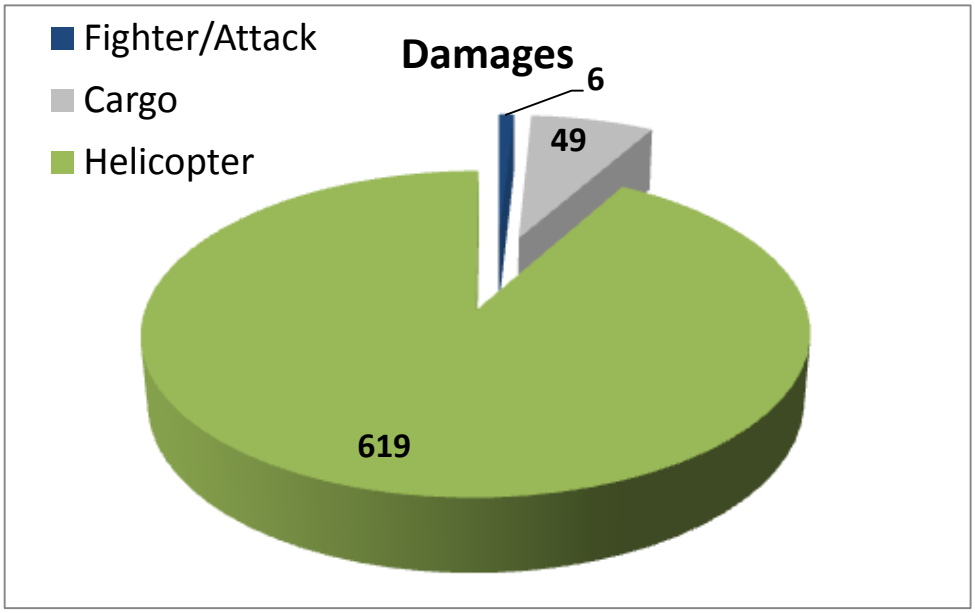

Figure 5: Total US Aircraft Battle Damage By Type, 1998 - 2009

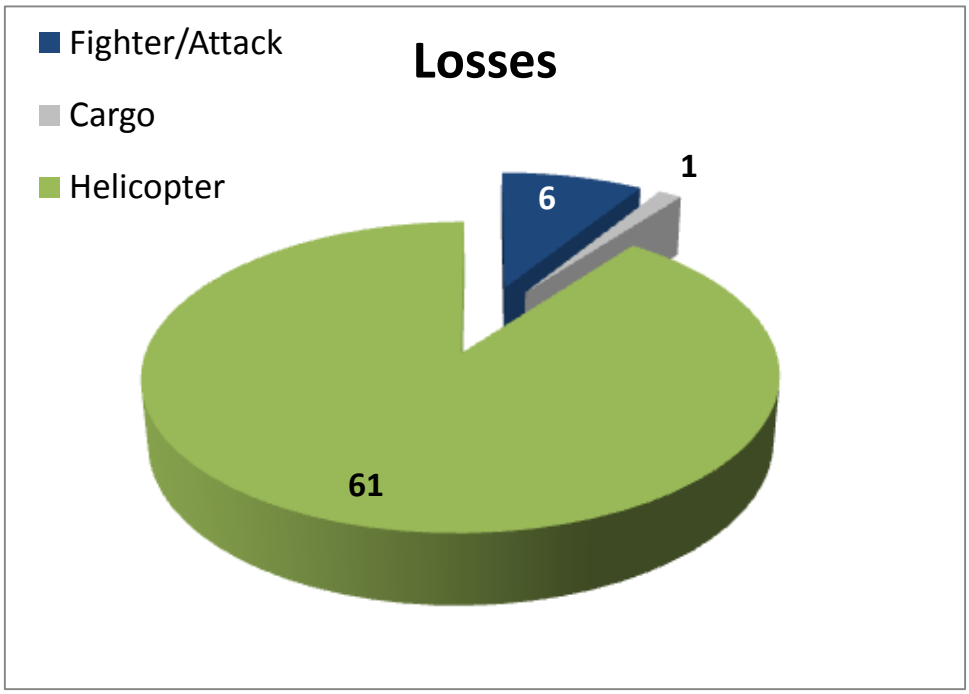

Figure 6: Total US Aircraft Battle Losses By Type, 1998 - 2009

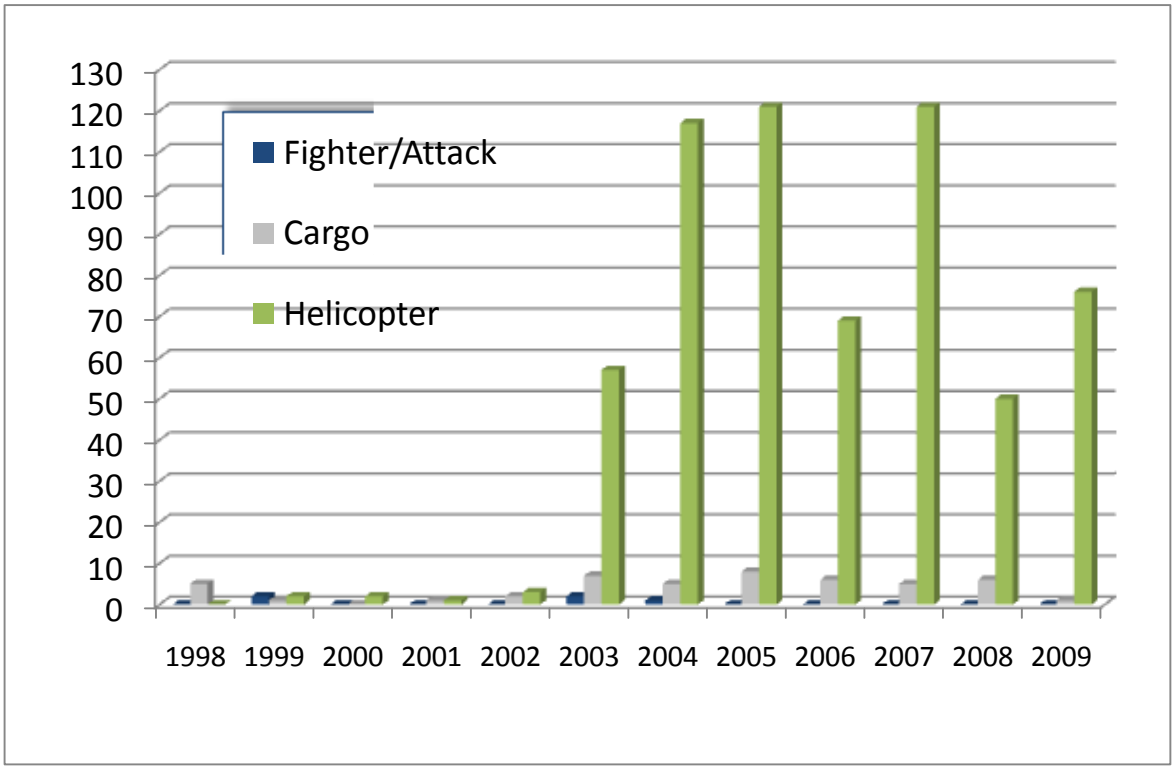

Figure 7: US Aircraft Battle Damages By Type and Year, 1998 – 2009

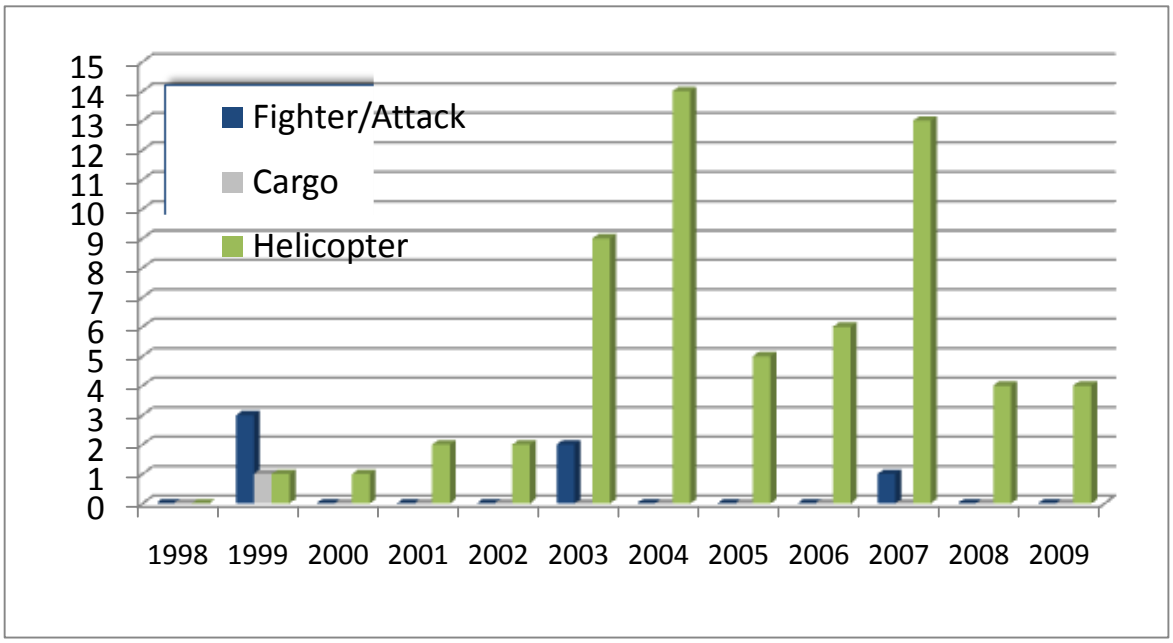

Figure 8: US Aircraft Battle Losses by Type and Year, 1998 - 2009

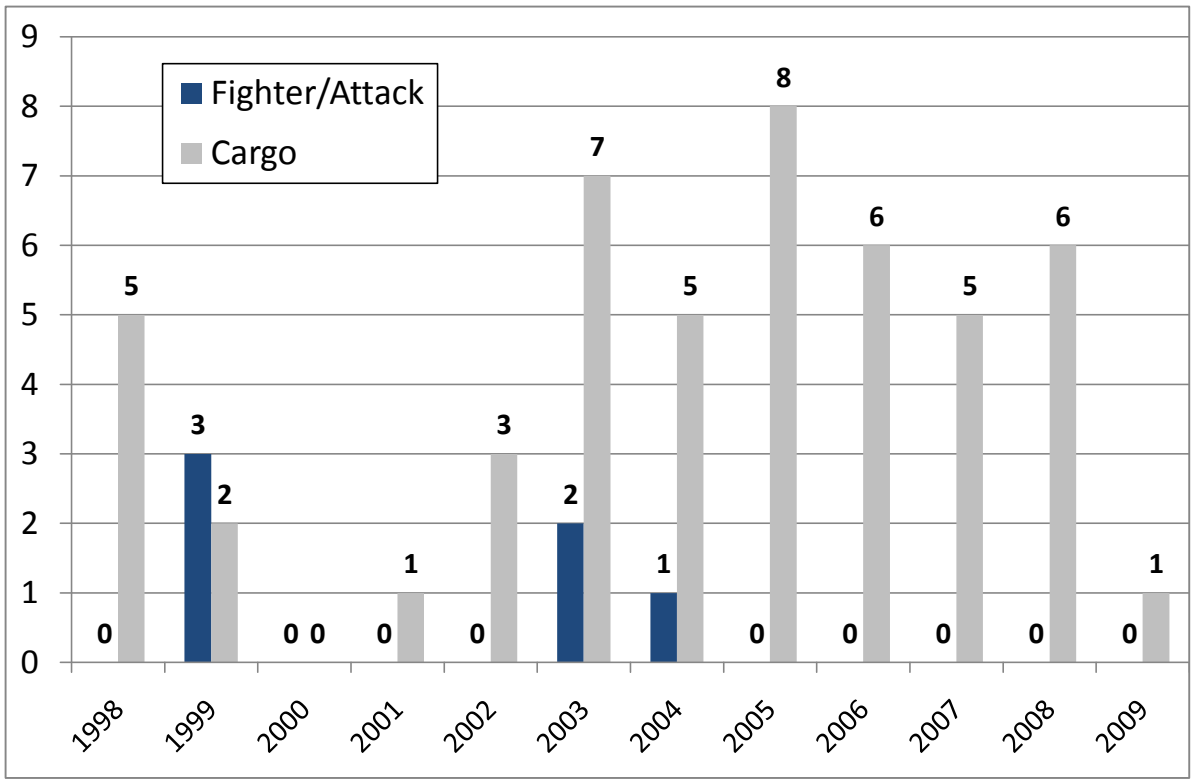

Figure 9: US Fixed-Wing Aircraft Battle Damages By Type and Year, 1998 – 2009

No specific data is provided for the repair rate of battle-damaged aircraft from 1998 – 2009, but it is safe to assume all of the aircraft identified as damaged versus lost were eventually repaired and returned to operational use. Current USAF ABDR methodology is in a state of change where ABDR is no longer conducted exclusively by CLSS teams and dedicated ABDR engineers. Since 2004, military Depot Liaison Engineers (DLEs), aircraft structural engineers with ABDR training and depot experience, have been deployed to USAF expeditionary aircraft maintenance units to support all levels of maintenance needs beyond organizational capability. This support includes assessing and designing repairs for battle damage to be implemented by organizational maintenance technicians or deployed CLSS field teams, depending on complexity. While ABDR training is at the foundation of the DLE concept, non-combat damage repairs constitute the bulk of the DLE workload. This is illustrated by DLE compiled data for 2009 which show USAF DLEs addressed over 1290 requests for maintenance assistance with only 77 total US aircraft battle damage incidents occurring during the same year, 76 of which were helicopter damages and likely not addressed by USAF DLE personnel.

4.0 CONCLUSION

Though the specifics of battle damage vary by conflict parameters like achievement of air superiority and the type of aircraft employed in the conflict, aircraft battle damage occurs in any conflict employing combat aircraft. History has shown the importance of aircraft battle damage repair to sustain viable aircraft fleets during a number of conflicts. US battle damage data since 1998 and before reflects the frequency of aircraft battle damage and supports the need to sustain an established ABDR program.

5.0 REFERENCES

[1] Maj Darrell H. Holcomb, USAF, "Aircraft Battle Damage Repair for the 90s and Beyond," Air Research Institute Report, March 1994

[2] "The 401st Bombardment Group." *www.remember-our-heroes.nl/us-401st.htm.*2009. Accessed 25 November 2009.

[3] Lt Col William H. Foster II, USAF, "Aircraft Battle Damage Repare [sic] (ABDR) 2000: Will ABDR Become the Logistics Center of Gravity by the Year 2000?," Air War College Report, May 1989

[4] Srull, Donald W., "Battle Damage Repair of Tactical Weapons: An Assessment", Logistics Management Institute Report, Aug 1989

[5] AFMCH 62-XXX, Aircraft Battle Damage Repair Engineering, Draft USAF Military Handbook, 31 January 2004